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**APPLICATION FOR
UNITED STATES UTILITY LETTERS PATENT**

Be it known that we, Kok S. Chen, a citizen of Thailand, residing at 870 E. El Camino Real, #425, Sunnyvale, County of Santa Clara, and State of California 94087 of the United States of America, and Gabriel G. Marcu, a citizen of Romania, residing at 1249 Runnymede Drive, San Jose, County of Santa Clara, and State of California 95117 of the United States of America, have invented certain new and useful improvements in a

**SYSTEM AND METHOD FOR HALFTONING USING A TIME-
VARIABLE HALFTONE PATTERN**

of which the following is the Specification:

I hereby certify that this correspondence is being deposited with the United States Postal Service as Express Mail No. EL339226745 US in an envelope addressed to: BOX PATENT APPLICATION, Assistant Commissioner for Patents, Washington, D.C. 20231, on June 25, 1999.

Nancy R. Smorin
(Signature)

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to the field of image reproduction, and more particularly, to halftoning. Still more particularly, the present invention relates to a system and method for halftoning using a time-variable halftone pattern.

2. Description of the Prior Art:

Bi-level and multi-level devices have limited tonal range. Intermediate tones, such as varying shades of gray, must be represented by halftones. Halftoning is a process by which continuous-tone colors are approximated by a pattern of pixels that can achieve only a limited number of discrete colors. The most familiar case of this is the rendering of gray tones with black and white pixels, as in a newspaper photograph.

There are many conventional techniques for halftoning. Dithering, stochastic screens, and error diffusion are all different types of halftoning techniques. When a particular halftoning technique is used, the resulting image is comprised of halftone patterns. In other words, halftone patterns are what the halftoning techniques create.

Contemporary halftoning techniques have parameters specific to each technique. For example, dithering techniques include order and unordered dithering. Error diffusion is an example of unordered dithering. Ordered dithering is usually implemented using a threshold array. Furthermore, ordered dithering can be further sub-categorized into clustered or dispersed dot dithers.

With clustered dot dithering, the arrangement of the gray levels tends to result in the formation of clumps or clusters. With dispersed dot

1 dithering, the successive gray threshold values in the array are spread or
2 dispersed away from each other as much as possible. Stochastic screens are a
3 class of dispersed dot dithering in which the appearance of the halftoned
4 result is similar to that of an unordered dither. Stochastic screens are
5 preferred over unordered dithering in that it has much better computational
6 efficiencies (both in time and in memory usage).
7

8 When an image is halftoned, the parameter or parameters (i.e.,
9 ordered, threshold array) specific to the halftoning technique remains
10 constant during the halftoning process. For example, the same array is used
11 each time the image is halftoned.
12

13 For display devices, such as computer monitors and televisions, images
14 are presented as frames that are refreshed or repeated many times a second.
15 This refreshing or repeating of the image occurs regardless of whether the
16 image itself is changing over time. So, for a picture displayed on a computer
17 monitor, a movie played on television, or a movie played in a theater, each
18 frame is refreshed or repeated many times a second.
19

20 However, as discussed earlier, the parameters in contemporary
21 halftoning techniques remain constant while each frame is repeated. This
22 can create artifacts in the image, in that the halftone patterns become visible
23 to the human eye. This is especially true for animated images, because the
24 halftone pattern remains fixed over time while the frames in the image
25 move and change over time.
26

SUMMARY OF THE INVENTION

The present invention overcomes the limitations of the prior art by providing a system and method for halftoning using a time-variable halftone pattern. Successive frames that are presented to the output device are individually halftoned. The halftone pattern is changed from frame to frame. The different halftone patterns can be generated in real time, or they can be calculated prior to halftoning and stored in memory. Additionally, the halftone patterns can be generated using any conventional halftoning technique. The same halftoning technique can be used to create each halftone pattern, or the halftoning techniques can be varied when creating halftone patterns. The halftoned frames are then viewed in a sequence in time. Because the halftone pattern is changing from frame to frame, the visibility of the pattern is reduced when compared with the patterns produced by prior art halftoning methods.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, and further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an exemplary block diagram of a general purpose computer system that can be used to implement the present invention;

Figure 2a illustrates an exemplary image comprised of pixels;

Figure 2b depicts an exemplary halftone mask comprised of threshold values;

Figures 3a-3f illustrate an exemplary prior art method for halftoning;

Figure 4 depicts an exemplary method for halftoning using a time-variable halftone mask according to the present invention;

Figures 5a-5d illustrate an alternative exemplary method for halftoning using a time-variable halftone mask according to the present invention; and

Figures 6a-6i depict an exemplary sequence of halftoned frames of constant gray of 95% luminance, created by halftoning with a time-variable halftone mask according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

To facilitate an understanding of the present invention, it is described hereinafter in the context of a specific embodiment. In particular, reference is made to an implementation of the invention on a computer display where the image being displayed is halftoned using a halftone mask as the halftoning technique. It will be appreciated, however, that the practical applications of the invention are not limited to this particular embodiment. Rather, the invention can be employed in other types of output devices, such as televisions and movie players. Furthermore, the present invention is not limited to the use of halftone masks as the halftoning technique. Other halftoning techniques, such as dithering or error diffusion, can be used.

With reference now to the figures and in particular with reference to **Figure 1**, a general purpose computer system that can be used to implement the present invention is illustrated. Computer system **100** includes a central processing unit (CPU) **102** that typically is comprised of a microprocessor, related logic circuitry, and related memory circuitry. Input device **104** provides input to CPU **102**, with examples of input devices including a keyboard, mouse, or stylus. Communications port (Com. Port) **106** is used for interfacing with other processors and communication devices, such as modems and area networks. Program memory **108** contains operating instructions for directing the control of CPU **102**. Mass storage **110** contains stored data that is utilized by CPU **102** in executing the program instructions from program memory **108**. And finally, computer monitor **112** outputs data and information to a user.

Figure 2a illustrates an exemplary image comprised of pixels. Image 200 is shown as a 12x12 image comprised of 144 pixels. Pixels are usually arranged on an orthogonal grid, with the pixels placed at evenly spaced lattice points. Typically image 200 is associated with the (x,y) coordinate system, with the rows as the x coordinate and the columns as the y coordinate. Pixel 202 is usually considered the pixel in the (0,0) location. With pixel 202 at (0,0), pixel 204 is located at (7,5) and pixel 206 is positioned at (10,11) in the image.

1
2 Referring to **Figure 2b**, an exemplary halftone mask comprised of
3 threshold values is shown. Mask **208** is illustrated as a 3x3 mask comprised of
4 9 threshold values. In order to determine whether a pixel in image **200** is
5 "on" or "off", an imaging device checks a pixel's address (i.e. it's (x,y)
6 location), determines the tonal value of the image at that address, and
7 compares that tonal value with it's corresponding threshold value in the
8 halftone mask. If the tonal value of the pixel exceeds the threshold value in
9 the halftone mask, the pixel is turned "on" when the image is displayed on
10 the computer monitor.

11
12 For example, in order to determine whether pixel **202** is "on" or "off",
13 an imaging device checks the address of pixel **202**, which in this example is
14 (0,0), determines the tonal value at that address, and compares that tonal
15 value with the threshold value **210** in halftone mask **208**. If the tonal value
16 of pixel **202** exceeds the threshold value **210**, pixel **202** is turned "on" when
17 the image is displayed.

18
19 **Figures 3a-3f** illustrate an exemplary prior art method for halftoning.
20 Image **300** is shown as a 9x6 image, comprised of 54 pixels. Threshold array
21 **302** is represented as a 3x3 array, and is comprised of threshold values. Pixel
22 **304** in image **300** (**Figure 3a**) is the pixel located at (0,0). When halftoning
23 occurs, threshold array **302** is replicated and "tiled" (i.e., filled in a non-
24 overlapping manner) over the entire image **300**. **Figures 3a-3f** illustrate the
25 process of halftoning by tiling threshold array **302** over image **300**.

26
27 For a computer monitor, threshold array **302** is tiled over image **300** in
28 a raster pattern. In other words, threshold array **302** is initially placed at the
29 (0,0) location in image **300**. It is then tiled along the first three rows until
30 threshold array **302** reaches the end of the rows. This process is shown in
31 **Figures 3a** through **3c**. Once the end of the first three rows is reached,
32 threshold array **302** is then moved to the start of the next three rows. This
33 would place the upper left-hand corner of threshold array at pixel **306**. Again,
34 threshold array **302** is tiled along the next three rows until threshold array
35 **302** reaches the end of the rows. This process is shown in **Figures 3d** through

1 3f. Image 300 is now halftoned, because in this example, image 300 is a 9x6
2 image, so there are no more pixels left to halftone. Obviously, tiling
3 threshold array 302 in this manner would continue if image 300 was larger.
4

5 In this prior art method of halftoning, threshold array 302 remains
6 constant while the image is halftoned. For example, if the image is rendered
7 on a display, the image is halftoned each time the image is drawn to the
8 screen. In this situation, the halftone pattern does not change when the
9 image is drawn and re-drawn to the screen because the same threshold array
10 is used to halftone the images.
11

12 Figure 4 depicts an exemplary method for halftoning using a time-
13 variable halftone mask according to the present invention. Image 400 is to be
14 halftoned using four separate and independent halftone masks 402, 404, 406,
15 408. Halftone masks 402, 404, 406, 408 were created independent of one
16 another and are preferably stored in memory. When image 400 is to be
17 halftoned, halftone mask 402 is used first to halftone image 400. Preferably,
18 halftone mask 402 is placed at the initial pixel 410 and then tiled over the
19 entire image. Halftone mask 404 is then selected and tiled over the image,
20 followed by halftone mask 406. Finally, halftone mask 408 is selected and
21 tiled over image 400. The halftoned images are then viewed in a continuous
22 sequence in time. Because the halftone pattern changes from one image to
23 the next, the visibility of the pattern is reduced compared with the patterns
24 created by prior art methods.
25

26 This exemplary method is not however, limited to only four halftone
27 masks. Any number of halftone masks can be used. Those skilled in the art
28 will appreciate that the flicker period can be reduced by increasing the number
29 of halftone masks. Furthermore, halftone masks 402, 404, 406, 408 do not
30 have to be stored in memory. They can be calculated in real time.
31

32 Figures 5a-5d depict an alternative exemplary method for halftoning
33 using a time-variable halftone mask according to the present invention. In
34 this example, only one halftone mask is used to generate different halftoned
35 frames, where the frames are combined to create the output image. Different

1 (x,y) offsets are used to place the mask in the input image in order to generate
2 a halftoned frame.

3
4 ~~In Figure 5a, image 500 is a 9x9 image, and is comprised of 81 pixels.~~
5 Pixel 502 is located at the (0,0) position in image 500. Halftone mask 504 will
6 be used to halftone image 500. In this example, halftone mask 504 is a 3x3
7 array, comprised of nine threshold values. Halftone mask 504 is placed at the
8 initial location (0,0) in image 500, and is then used to halftone the image by
9 tiling halftone mask 504 over the entire image. This creates the first
10 halftoned frame. In Figure 5b halftone mask 504 is offset to location (7,6) in
11 the image. The second halftoned frame is created when image 500 is
12 halftoned again.

13
14 ~~Halftone mask 504 is then offset again to location (4,7), represented in~~
15 ~~Figure 5c by pixel 508. Image 500 is again halftoned, and a third frame is~~
16 ~~produced. Finally, in Figure 5d, halftone mask 504 is offset to pixel 510,~~
17 ~~located at (7,2), and a fourth halftoned frame is created. The resulting~~
18 ~~halftoned frames are then displayed in a sequence, thereby creating the output~~
19 ~~image. This process of changing the offsets of halftone mask 504 within~~
20 ~~image 500 repeats until halftoning is complete.~~

21
22 With reference now to Figures 6a-6i, an exemplary sequence of
23 halftoned frames of constant gray of 95% luminance, created by halftoning
24 with a time-variable halftone mask according to the present invention are
25 shown. A halftone mask comprised of 128x128 threshold values was used to
26 create the 40x30 halftoned frames shown in Figures 6a-6i.

27
28 ~~The halftoned frame shown in Figure 6a was created by positioning the~~
29 ~~halftone mask at location (38,28) in the image and then halftoning the image.~~
30 ~~The halftone mask is offset to to location (33,25) in the image and the image is~~
31 ~~halftoned a second time, resulting in the halftoned frame shown in Figure 6b.~~
32 A third halftoned frame illustrated in Figure 6c is then generated by offsetting
33 the halftone mask to location (11,17) in the image. Continuing with this
34 process, the halftoned frames shown in Figures 6d, 6e, 6f, 6g and 6h are

1 generated by offsetting the halftone mask to locations (10,9), (12,6), (29,17),
2 (4,0), and (25,23), respectively.
3

4 In the embodiment represented in **Figure 6**, the sequencing of
5 halftoned frames then repeats itself. **Figure 6i** was created by using the same
6 offset that was used for **Figure 6a**. As can be seen, the halftoned frame in
7 **Figure 6i** is the same as the halftoned frame in **Figure 6a**. This offsetting of
8 the halftone mask is repeated until the displayed output image is no longer
9 needed.
10

11 The present invention, however, is not limited to offsetting the
12 threshold mask. Different rotations, or transformations applied to the
13 halftone mask can be used as an alternative to offsetting the halftone mask.
14

15 The image being halftoned by the methods described with reference to
16 **Figures 4-6** can be animated or static. If the image is animated, different
17 halftone masks can be used on each frame, or a sequence of halftone masks
18 can be used in a continuous loop. Those skilled in the art will appreciate that
19 through the appropriate selection of differing halftone masks over time, the
20 flicker normally associated with prior art halftoning techniques can be
21 significantly reduced. A set of halftone masks can be selected so as to
22 minimize the temporal correlation. In fact, the halftone masks can be chosen
23 such that any spatial location, when viewed in time, would have minimal
24 correlation.
25

26 The method used to obtain the halftoned frames, however, is not
27 limited to thresholding by halftone masks. Any spatial halftoning technique,
28 acting on an area larger than a pixel, can be used with the present invention
29 by simply varying the halftoning parameters over time to create different
30 halftone frames to be viewed in sequence. The halftone pattern needs to
31 change from one frame to the next. This causes the visibility of the halftone
32 pattern to be reduced when the sequence of frames is displayed.
33

34 Furthermore, the process of halftoning according to the present
35 invention does not require the same halftoning technique to be used each

1 time an image is halftoned. Alternatively, the halftoning techniques can be
2 varied each time the image is halftoned. For example, dithering, stochastic
3 screening, and error diffusion techniques can be used on the same image,
4 simply by varying the particular technique used over time.
5

6 If the amount of time required to halftone a frame is less than the
7 period between frames, the halftoning process can be performed in real time,
8 regardless of whether the image to be displayed is static or animated. If the
9 amount of time required to halftone a frame is more than the period between
10 frames, an entire sequence of halftoned animated images may have to be pre-
11 computed, stored, and subsequently replayed. For a static image, a sequence of
12 halftoned frames can be stored and replayed in a continuous loop. Since the
13 present invention can be implemented in hardware, software, or a
14 combination of the two, the speed of the halftoning process can be optimized
15 by implementing the invention in a design that is appropriate for a particular
16 system.
17

18 And finally, the present invention is not limited to use for images
19 displayed on a computer monitor. Those skilled in the art will appreciate that
20 the present invention can be used in other types of output devices, such as
21 televisions and movie players. The present invention can also be used with
22 computer applications, such as games, movies, and displaying and
23 transmitting images over communication channels, such as the Internet.
24